Characteristics of motor cortical activity in reaction time task

H. Endo[1,2], Y. Kato[3], T. Kizuka[4], T. Masuda[4,2], and T. Takeda[5,2]

[1]*Human Informatics Dep., National Inst. of Bioscience and Human-Technology, Ibaraki, Japan;*
[2]*Core Res. for Evolutional Science and Technology, Japan Science and Technology Corp., Saitama, Japan;*
[3]*Health and Sport Science, University of Tsukuba, Ibaraki, Japan;*
[4]*Human-Environment System Dept., National Inst. of Bioscience and Human-Technology, Ibaraki, Japan;*
[5]*Dept. of Complexity Science and Engineering, University of Tokyo, Tokyo, Japan*

1 Introduction

The study of human brain mechanism in cognitive science has become active recently due to the advancement of non-invasive brain measurement methods. In some experimental studies, reaction time tasks like button press have been used to analyze cognitive performance. However, few studies have been done to examine the human brain mechanism in the reaction time task. It has been reported in fMRI and PET studies that there are some differences in the motor activity between a self-paced movement (SPM) and an externally triggered movement (ETM) [1, 2]. Although there have been reported many MEG studies related to SPM [3, 4], not much is known about motor activity during ETM [5, 6]. By the way, it was recently reported that the primary motor cortex (MI) was not only structurally [7, 8] but also functionally inhomogeneous [7] and was differently activated depending on the task. It is important, not only for the motion control study but for the cognitive science, to examine the change of activity pattern in MI depending on the movement execution. The supplementary motor area (SMA) and the premotor area (PMA) are difficult to be examined with MEG [3, 9]. However, MEG recording has high sensitivity for the tangential components of neuron activities and this is a useful method to measure the activity in MI. We have already reported the motor activity synchronized with the external visual Go-stimulus [6]. This study focused on the brain activity related to movement execution and examined the motor activity differences between SPM and ETM.

2 Methods

2.1 Subjects and tasks

The experiments were carried out on 6 right-handed normal subjects (male, aged 24-34). Right and left finger movements were performed in the movement task. The movement was a brisk index finger abduction. Experimental conditions were as follows:

1) Self-paced movement (SPM task): The subject starts the movement at free intervals over 5 s.
2) Visually triggered movement with an LED Go-stimulus (VTM task): The subject starts at the lighting of the green LED Go-stimulus. The stimulus interval was around 6+/-1 s.
3) Visual no-movement experiment with passive LED stimulus observation (VEF experiment): ISI = 2+/-1 s.

Right and left finger movements were done in the different sessions. A hundred movements were carried out in each movement task. Repeatability was checked on different days.

The brain magnetic fields were recorded using a 64-channel whole-cortex MEG system (CTF Systems Inc., Canada). Data were acquired at a rate of 250 samples/s with a 40 Hz low-pass filter. EMG from the first dorsal interosseous muscle was also recorded simultaneously.

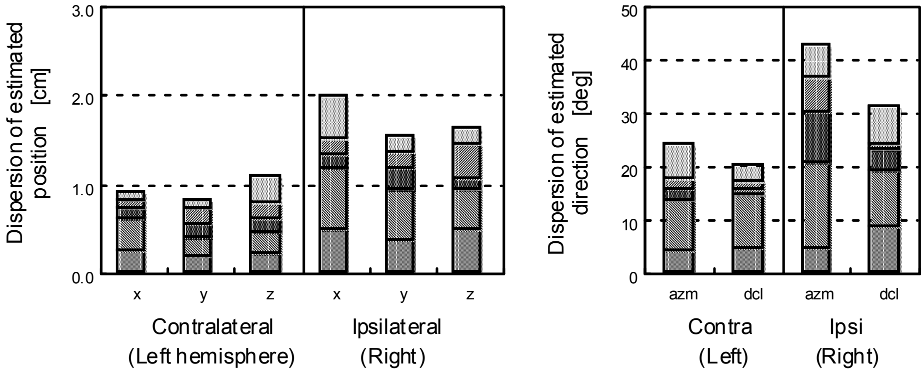
2.2 Data analysis

Averaging of MEG data, after elimination of artefact-contaminated trials, was done off-line with respect to the movement onset. The onset of the rectified EMG burst was used as a trigger to synchronize the movement onset averaging. In the VTM task, the reaction time was measured from the stimulus onset to the rectified EMG onset and classification of trials into groups with similar reaction times was done. All trial data in each recording were lined up in order of the reaction time and classified based on the reaction time. Averaging was done not only for all trial data (all trial averaging, ATA) but for all classified trial data (reaction time classified averaging, RTA). The time range of the reaction time for each class was not fixed, but the number of trials classified in each average was adjusted to be 30~40 to make the signal-to-noise ratio similar. The first 500 ms prior to the stimulus onset was used as a baseline for the averaged data. The averaged data were filtered with a zero phase shift, 30 Hz low-pass filter.

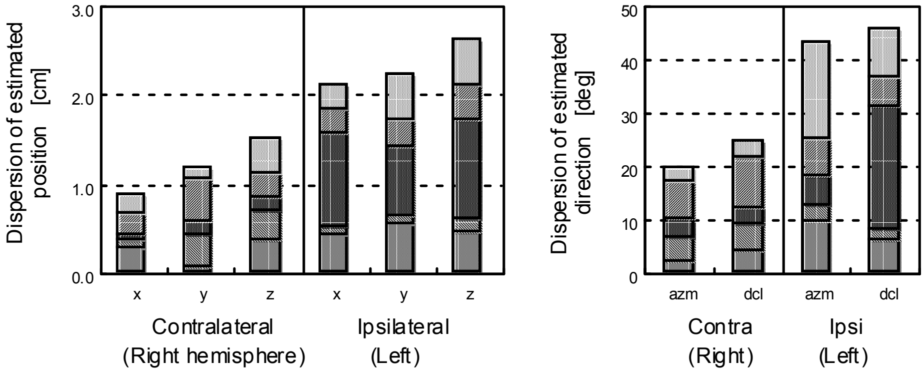
All brain activities were examined with an equivalent current dipole (ECD) model. In order to calculate the time course of the activity, we hypothesized that the locational change of the activity area was small enough to allow evaluation of the temporal features of the activity during the analysis period. The ECD was assumed to be fixed at the most probable position during the analysis period. In the VTM task, dipole position was estimated form ATA data, and the time course was calculated form RTA data.

3 Results

In the SPM task, the readiness field (RF) started bilaterally 500-1000 ms prior to the movement onset and isocontour maps of the magnetic field from the start of RF to EMG onset did not change in pattern (5 in 6 subjects). Then, the locational parameters of the motor dipoles during RF were examined. Estimation using a 2-dipole model in the both hemispheres was done from -300 ms to 40 ms. This time window was divided into 10 sub-windows: -300~-200 ms, -200~-140 ms, -140~-100 ms and 20 ms intervals from -100 ms to 40 ms. The locations of dipoles were estimated minimizing the cumulative error in each sub-window. The dipoles estimated with error < 10% were analyzed. The dipoles contralateral to the movement side were gathered in a small cluster (5/6). On the other hand, the ipsilateral dipoles were scattered. Fig. 1 indicates the dispersion of the estimated dipole position and direction in five subjects. There was a significant difference in the dispersion whether they existed in the contralateral side or in the ipsilateral side. However, there was no significant difference whether they were in the right hemisphere or in the left hemisphere, though all subjects were right-handed. As for the dipoles estimated in the same hemisphere for the contralateral and ipsilateral movements, the position and direction shifted slightly (4/6), and in one subject, the dipoles were estimated in completely different location.

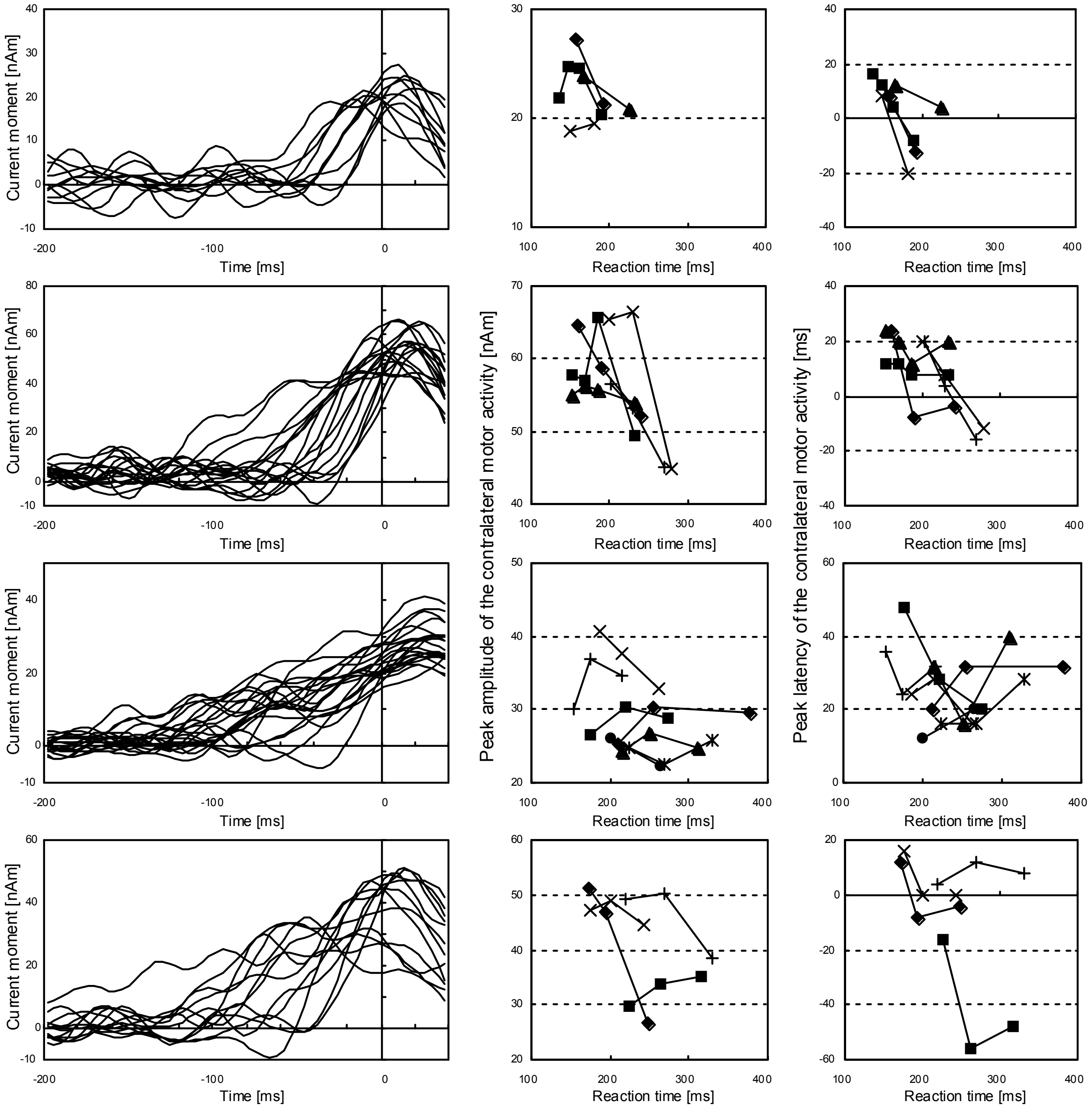


(a) Right finger movement



(b) Left finger movement

Figure 1: *Dispersion of locational paramerters of the motor dipoles in the SPM task. Dispersion was defined by the standard deviation of estimated value of 10 time windows. x is a coordinate axes in sagital direction, y is in coronal direction, z is in axial direction and azm is an angle from x-axis, dcl is an angle from z-axis. (a) Right finger movement. (b) Left finger movement.*



(a) Time courses of the motor activity

(b) Relation between the peak amplitude and the reaction time

(c) Relation between the peak latency and the reaction time

Figure 2: *Time courses of the motor activity and relationship between the motor activity and the reaction time. Results of four subjects are shown. (a) Time courses calculated from each RTA data. (b) Relationship between the peak amplitude and the reaction time. (c) Relationship between the peak latency and the reaction time. Each line in (a) and each plot in (b)&(c) correspond to the result estimated from each RTA data.*

The iso-field pattern of the VTM task was similar to the SPM task in the contralateral side. The subject who showed strong RF in the SPM task showed clear and similar bilateral activity in the VTM task. However, the estimated locations of the motor dipole in the SPM task and the VTM task did not always coincide. The dipole in the contralateral side was estimated in the relatively close position, but there was also a tendency to be localized slightly posterior. This might be caused by the influence of VEF activity. The ipsilateral activity was sometimes unclear, and the motor dipole could not be determined.

Next, the relationship between the motor activity and the reaction time was examined. The time course of the motor activity was calculated from each RTA data. There was a relation between the contralateral motor activity and the reaction time. As shown in Fig.2, the faster the reaction time became, the stronger the activity strength was. The faster the reaction time became, the later the peak latency of the activity became. In the case of long reaction time, the onset of the contralateral activity became gentle.

4 Discussion

In the SPM task, although the RF is bilateral activity where the activities in both sides are going up in the same way, the side not related to movement execution showed low dipolarity and there was evident difference in localization accuracy. We speculated that the source area of ipsilateral activity was spread out, though the contralateral activity was more concentrated. Then, it was conjectured that the contralateral and ipsilateral activities reflected the different activation mechanism.

In the SPM task, since the preparation starts internally, it is speculated that the synchronicity of the onset of preparation is bad and the activity onset will be gentle. On the other hand, in the VTM task, since the subject can't expect the timing of stimulus, the motor activity rapidly starts synchronized with the external trigger. However, when the reaction was delayed and the synchronicity became worse, the onset of the motor activity became gentle. Besides, the subject who showed strong RF in the SPM task showed clear bilateral motor activity in the VTM task. For these reasons, it was conjectured that the motor activity observed in the VTM task was same as the part of RF which had higher synchronous and was shorten in time scale.

In this study, significant locational changes of the dipoles in the SPM task and the VTM task could not be found. However, the different activation pattern of the motor activity could be estimated.

References

1. H. Boecker, A. Kleinschmidt, M. Requardt, W. Hänicke, K.D. Merboldt and J. Frahm, "Functional cooperativity of human cortical motor areas during self-paced simple finger movements: A high-resolution MRI study", *Brain*, **117**, 1231-1239, 1994.
2. J. Larsson, B. Gulyás and P.E. Roland, "Cortical representation of self-paced finger movement", *Neuroreport*, **7**, 463-468, 1996.
3. R. Kristeva, D. Cheyne and L. Deecke, "Neuromagnetic fields accompanying unilateral and bilateral voluntary movements: topography and analysis of cortical sources", *Electroenceph. clin. Neurophysiol.*, **81**, 284-298, 1991.
4. M. Hoshiyama, R. Kakigi, P. Berg, S. Koyama, Y. Kitamura, M. Shimojo, S. Watanabe and A. Nakamura, "Identification of motor and sensory brain activities during unilateral finger movement: spatiotemporal source analysis of movement-associated magnetic fields", *Exp. Brain Res.*, **115**, 6-14, 1997.
5. A. Nambu, R. Matsuzaki, H. Gemba and K. Sasaki, "Magnetic fields in the cerebral cortex associated with visually initiated finger movements in human subjects", in Biomagnetism:Functional research and clinical applications, C. Baumgartner, L. Deecke, G. Stroink and S.J. Williamson, Eds. Amsterdam: Elsevier, 1995, pp.141-144.
6. H. Endo, T. Kizuka, T. Masuda and T. Takeda, "Automatic activation in the human primary motor cortex synchronized with movement preparation", *Cogn. Brain Res.*, **8**, 229-239, 1999.
7. S. Geyer, A. Ledberg, A. Schleicher, S. Kinomura, T. Schormann, U. Bürgel, T. Klingberg, J. Larsson, K. Zilles and P.E. Roland, "Two different areas within the primary motor cortex of man", *Nature*, **382**, 805-807, 1996.
8. T. M. Preuss, I. Stepniewska, N. Jain and J.H. Kaas, "Multiple divisions of macaque precentral motor cortex identified with neurofilament antibody SMI-32", *Brain Res.*, **767**, 148-153, 1997.
9. W. Lang, D. Cheyne, R. Kristeva, R. Beisteiner, G. Lindinger and L. Deecke, "Three-dimensional localization of SMA activity preceding voluntary movement. A study of electric and magnetic fields in a patient with infarction of the right supplementary motor area", *Exp. Brain Res.*, **87**, 688-695, 1991.